

*EFFECTS OF VARIABLE-INTERVAL VALUE AND
AMOUNT OF TRAINING ON
STIMULUS GENERALIZATION*

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In Experiment 1 pigeons pecked a key that was illuminated with a 501-nm light and obtained food by doing so according to a variable-interval (VI) schedule of reinforcement, the mean value of which differed across groups: either 30 s, 120 s, or 240 s. The pigeons in all three groups were trained for 10 50-min sessions. Generalization testing was conducted in extinction with different wavelengths of light. Absolute and relative generalization gradients were similar in shape for the three groups. Experiment 2 was a systematic replication of Experiment 1 using line orientation as the stimulus dimension and a mean VI value of either 30 s or 240 s. Again, gradients of generalization were similar for the two groups. In Experiment 3 pigeons pecked a key that was illuminated with a 501-nm light and obtained food reinforcers according to either a VI 30-s or a 240-s schedule. Training continued until response rates stabilized (>30 sessions). For subjects trained with the 30-s schedule, generalization gradients were virtually identical regardless of whether training was for 10 sessions (Experiment 1) or until response rates stabilized. For subjects trained with the VI 240-s schedule, absolute generalization gradients for subjects trained to stability were displaced upward relative to gradients for subjects trained for only 10 sessions (Experiment 1), and relative generalization gradients were slightly flatter. These results indicate that the shape of a generalization gradient does not necessarily depend on the rate of reinforcement during 10-session single-stimulus training but that the effects of prolonged training on stimulus generalization may be schedule dependent.

Key words: stimulus generalization, generalization gradient, reinforcement rate, amount of training, variable-interval schedule, key peck, pigeons

The shape of a stimulus-generalization gradient depends on the procedures used to generate it and the training conditions in effect before the test for generalization occurs (Harrison, 1991; Mednick & Freedman, 1960; Rilling, 1977; Terrace, 1966). The present study focused on three factors that can influence the shape of a generalization gradient: (a) rate, or schedule, of reinforcement used to maintain responding during training, (b)

dimension of generalization, and (c) amount of training.

Hearst, Koresko, and Poppen (1964) performed two experiments in which the extent of stimulus generalization during testing was a function of the schedule of reinforcement used to maintain responding during training. In their Experiment 2, key pecking by pigeons was maintained in the presence of either a vertical or a horizontal line by a schedule of reinforcement in which key pecks were followed by food after some average amount of time (a variable-interval [VI] schedule). Five groups of pigeons differed with respect to VI schedule parameter; responding was maintained by a VI 30-s, a VI 60-s (these data were from Experiment 1 of their study, which used procedures identical to those in Experiment 2), a VI 120-s, a VI 180-s, or a VI 240-s schedule of food presentation. Ten to 11 sessions of training were conducted in which 30-s stimulus-on periods alternated with 10-s stimulus-off periods. During stimulus-on periods the houselight and keylight were illuminated, and the VI schedule was in effect. During stimulus-off periods the chamber was dark, and responding had no programmed consequences (i.e., extinction was in effect).

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These data were presented in a dissertation by the first author that fulfilled part of the requirements for the PhD degree. Portions of these data were presented at the 12th annual convention of the Southeastern Association for Behavior Analysis in Charleston, South Carolina, November 1995, and at the 22nd annual convention of the Association for Behavior Analysis in San Francisco, May 1996.

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The sessions were 50 min in duration and consisted of 75 stimulus-on/stimulus-off periods. Generalization testing was conducted in one session and consisted of a 10-min preliminary period during which training conditions were in effect. Then the training stimulus and lines of other orientations were presented during stimulus-on periods. Eight different line orientations were presented randomly during each of 10 blocks, and extinction was in effect. Results showed that the extent of generalization to other line orientations was an inverse function of the rate of reinforcement. The differences were substantial: Responding by subjects trained with infrequent reinforcement (VI 180 s, VI 240 s) almost completely generalized to the other stimuli (i.e., their generalization gradients were flat). Subjects trained with more frequent reinforcement (VI 30 s, VI 60 s) emitted many more responses in the presence of the training stimulus than in the presence of any of the stimuli not present during training, and their generalization gradients were steep.

Because subjects experienced an equal number of training sessions of the same duration but different VI schedule parameters, both the schedule (rate) of reinforcement and the total number of reinforcers earned during training differed for the different groups. The original purpose of the present set of experiments was to answer two questions: (a) Will the relation between intermittency of reinforcer delivery and extent of stimulus generalization hold when wavelength of light, rather than line orientation, is the stimulus dimension? (b) Is the difference in extent of generalization for the different groups attributable to the difference in number of reinforcers earned during training or to the schedule of reinforcement? In Experiment 1 we examined the first question by systematically replicating the Hearst et al. (1964) study using wavelength of light as the stimulus dimension. Because our results failed to replicate those reported by Hearst et al., Experiment 2 repeated the Hearst et al. procedure more closely using line tilt as the stimulus dimension. Results from Experiment 2 also did not resemble the effect reported by Hearst et al.; therefore, the second question was not addressed. We were still interested, though, in the possibility that the number

of reinforcers earned during training is a determinant of the extent of generalization. Our question was whether stimulus generalization is influenced by amount of training, and we were specifically interested in whether the Hearst et al. procedure would produce different results if subjects were trained for a longer period of time. In a typical operant conditioning experiment, subjects are trained until some measure of responding (e.g., response rate) is stable from session to session; however, in a typical stimulus-generalization experiment, testing occurs following a preset number of training sessions (e.g., 10 to 11). Experiment 3 examined the extent to which stimulus generalization is influenced by amount of training. The questions addressed by Experiment 3 were: (a) Does the extent of stimulus generalization depend on the amount of training? (b) Do generalization gradients differ for subjects trained to stability compared to those trained for the typical 10 to 11 sessions?

EXPERIMENT 1

The purpose of Experiment 1 was to see if the relation found by Hearst et al. (1964) between rate of reinforcement and extent of generalization would hold when wavelength, rather than line tilt, was the stimulus dimension. The procedures used by Hearst et al. were replicated closely except that the stimuli used in training and testing were different wavelengths of light rather than different orientations of a line. Three groups were studied: During training responding was maintained by VI 30-s, VI 120-s, or VI 240-s schedules of reinforcement in different groups of subjects.

Wavelength of light was chosen as the stimulus dimension in the present Experiment 1 because Haber and Kalish (1963) had compared gradients of generalization across the wavelength dimension and obtained results that differed from those of Hearst et al. (1964). In the study by Haber and Kalish, pigeons were trained to peck a key in the presence of a 550-nm light. Then, for different groups of pigeons, pecking was reinforced according to VI 15-s, VI 60-s, or VI 240-s schedules of reinforcement. Generalization testing was conducted in extinction with different wavelengths of light as the test stimuli. Figure

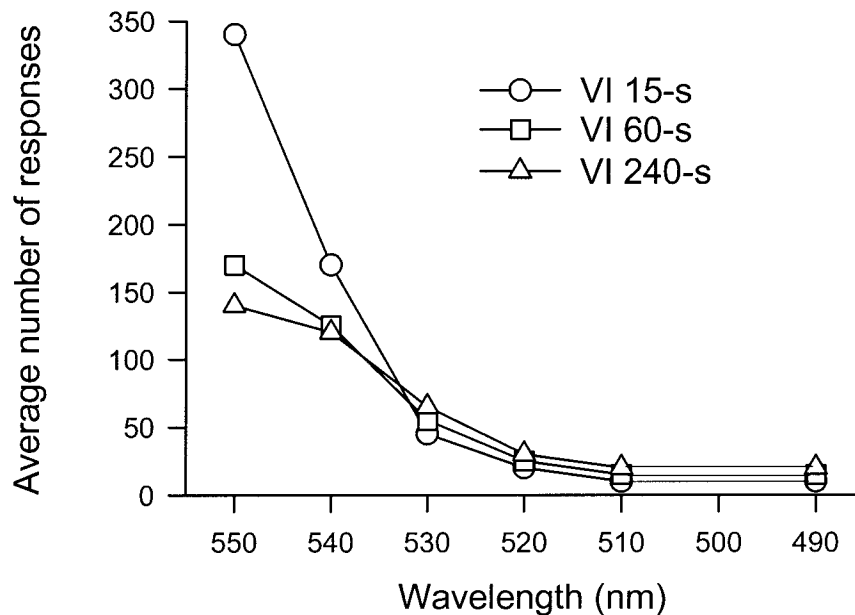


Fig. 1. Gradients of average absolute generalization for pigeons trained with a VI 15-s (circles), a VI 60-s (squares), or a VI 240-s (triangles) schedule of reinforcement in the presence of a 550-nm light. Absolute generalization refers to the total number of responses emitted in the presence of each test stimulus as a function of wavelength of the stimulus in nanometers. (From "Prediction of discrimination from generalization after variations in schedule of reinforcement," by A. Haber & H. I. Kalish, 1963, *Science*, 142, p. 413. Copyright 1963 by the American Association for the Advancement of Science. Adapted with permission.)

1 shows the results, replotted from Haber and Kalish (1963). Consistent with the trend reported by Hearst et al., the gradient for the VI 15-s subjects was steeper than the gradients for the other two groups. Nonetheless, the gradients obtained for the VI 240-s subjects differed markedly in steepness between the two studies. Whereas the gradients obtained for subjects trained with a VI 240-s schedule using line orientation as the stimulus dimension were almost completely flat (Hearst et al., 1964), the generalization gradient for the VI 240-s subjects tested with wavelength of light as the stimulus dimension was relatively steep (Haber & Kalish, 1963). This result suggests that the relation between VI mean interval and extent of generalization reported by Hearst et al. may not hold when wavelength of light is the stimulus dimension, at least not to the same degree.

Besides the dimension of generalization, there were other differences between the procedures used by Haber and Kalish (1963) and those used by Hearst et al. (1964). In the former study, training consisted of 60-s stimulus-on periods, whereas testing consisted of

30-s stimulus-on periods. In the Hearst et al. study, all stimulus-on periods were 30 s. Subjects in the experiment by Haber and Kalish experienced the same number of training sessions as subjects in the study by Hearst et al. (10); however, sessions were 30 min long in the former and 50 min in the latter study. Subjects were maintained at 80% (Haber & Kalish) or 75% (Hearst et al.) of their free-feeding weights. Haber and Kalish did not mention whether their test sessions began with a warm-up period, during which training conditions were in effect. Although these differences seem minor and unlikely to produce such a discrepancy in results of the two procedures, the present Experiment 1 was designed to replicate the procedures used by Hearst et al. closely in an attempt to extend the generality of their findings to the wavelength dimension. Besides the dimension of generalization, the only obvious procedural differences between the present Experiment 1 and the experiment by Hearst et al. were as follows: (a) Reinforcers consisted of 4-s rather than 5-s access to grain. (Based on the weight of our grain and the amount of weight pi-

geons typically gain when given 3-s access to grain in a session, we suspected that subjects might surpass their 75% free-feeding weights if given 5-s access to grain.) (b) Nine rather than eight stimuli were presented during the generalization test. (c) Only stimuli to the right of the training stimulus on the wavelength continuum were presented during the generalization test, as in the study by Haber and Kalish, rather than stimuli on both sides of the midpoint of the continuum, as in the study by Hearst et al.

METHOD

Subjects

Twelve adult experimentally naive White Carneau pigeons of indeterminate sex were maintained at 75% of their free-feeding weights via supplemental feeding of mixed grain after experimental sessions. The pigeons were housed in individual stainless steel cages in a temperature-controlled colony room under a 16:8 hr light/dark cycle. They had continuous access to water and health grit in their home cages.

Apparatus

Sessions were conducted in a conventional operant conditioning chamber for pigeons (Lehigh Valley Electronics, Model 1519C). The work area was 31 cm wide, 37 cm tall, and 35 cm deep. The walls were white, and the work panel was gray aluminum. A response key, 2.5 cm in diameter, was centered on the work panel 25 cm above the floor. The key required a force of approximately 0.19 N (19 g) to count as a response and produce a 50-ms feedback tone. A projector (Industrial Electronic Engineers, Inc., Model 10-OW78-1820-L) was situated behind the response key and included 1.1-W 28-VDC lamps that could project the stimuli in front of them onto the key. These stimuli included 10 Kodak Wratten filters, two each of filter numbers 65, 74, 99, 73, and 72B. "When illuminated by a standard tungsten illuminant (illuminant A, with a color temperature of 2848K) these filters have dominant wavelengths of 501, 538, 555, 576, and 606 nm, respectively" (Lyons & Klicpec, 1971, p. 232). For each stimulus presentation, two lamps were lit (Sylvania miniature lamps, number 1820, with a color temperature of approximately 2,800 to 3,000 K). The

illumination of nine different pairs of filters resulted in the projection of nine different dominant wavelengths of light on the key (501, 517, 538, 549, 555, 559, 576, 587, and 606 nm), based on Illuminant A. Each filter has different luminance transmittance characteristics; therefore, brightness was not equated across the different stimuli.

A 1.1-W 28-VDC lamp located behind an aluminum shield served as a houselight. It was located above the response key 2.5 cm from the ceiling of the chamber. Reinforcement was 4-s access to mixed grain, which was delivered through an aperture (6 cm by 5 cm) below the response key and 10 cm above the floor. The feeder was illuminated by a 1.1-W 28-VDC lamp during reinforcement, at which time the houselight and keylight were off. White masking noise was present in the room in which the chamber was located, and a ventilation fan mounted in the back wall of the chamber provided additional masking noise. There was an observation window in the door of the chamber. The window was completely covered, except for a small hole through which the pigeon could be observed.

A custom-built computer that operated under the ECRBasic control system (Walter & Palya, 1984) and that was interfaced with an IBM-compatible computer located in an adjacent room programmed contingencies and collected data. A Gerbrands Model C-3 cumulative response recorder provided continuous recording of responses, food deliveries, and stimulus-on/stimulus-off periods.

Procedure

Preliminary training. Sessions were conducted daily at about the same time each day. Preliminary training consisted of adaptation, magazine training, and key-peck shaping. Pigeons were placed in the chamber with only the houselight on for one to three 20- to 30-min sessions (adaptation). After training to eat from the food magazine (one to five 30- to 40-min sessions), key-peck shaping was accomplished via the method of differential reinforcement of successive approximations. The keylight was illuminated from behind by the 501-nm light (the training stimulus). Once a key peck had been emitted, a fixed-ratio (FR) 1 schedule of food presentation was in effect, under which every key peck resulted in the delivery of mixed grain. Key-

peck shaping lasted for one to five sessions. Shaping sessions lasted for about 30 min or until 40 to 50 reinforcers had been delivered. The FR 1 schedule was in effect until pigeons had received a total of 95 to 140 reinforcements (40 to 50 reinforcements per session).

Variable-interval training. Training with VI schedules of reinforcement followed the FR 1 condition. The 12 pigeons were assigned randomly to three groups of 4 subjects each. The groups differed according to the schedule of reinforcement in effect during training: key pecks were reinforced according to VI 30-s, VI 120-s, or VI 240-s schedules of food presentation. Sessions began with a 3-min blackout (all lights in the chamber off and no consequences for responding). Then 30-s stimulus-on periods alternated with 10-s stimulus-off periods. During stimulus-on periods the houselight was on and the keylight was illuminated with the 501-nm wavelength of light (the training stimulus), and the schedule of reinforcement was in effect. During stimulus-off periods blackout conditions were in effect (i.e., all lights in the chamber off and no consequences for responding), and the timer for the VI schedule was halted. The timer resumed where it left off when stimulus-on conditions were again in effect. Sessions lasted for 50 min (not including the time that the feeder was raised) and included 75 stimulus-on/stimulus-off periods. Variable-interval training conditions were in effect for 10 sessions. To ensure that responding was not extinguished during the transition from FR 1 to VI 120 s and VI 240 s, the first interval of the first session of VI training for these two groups was the shortest interval in the list of interval values. For the remaining sessions, interval values were selected randomly, as described below.

Intervals for the VI schedules came from a list of values determined by Catania and Reynolds' (1968) equation for generating constant-probability VI schedules. Ten interval values were generated for each VI. During sessions the list sampled randomly without replacement until all 10 values had been used, and then the process was repeated until the session ended. The data collected included responses during stimulus-on and stimulus-off periods, latencies to respond during stimulus-on periods, and reinforcer deliveries. Re-

sponse rate and reinforcer rate were calculated.

Generalization testing. Following a 3-min blackout, training conditions were in effect for 10 min (including 7.5 min of schedule time and 2.5 min of stimulus-off time). Then generalization testing began, and extinction was in effect. Thirty-second stimulus-on periods continued to alternate with 10-s stimulus-off periods. Ten blocks occurred in a single session, and each block consisted of nine stimulus presentations, one of each of the nine stimuli. The order of stimulus presentation was determined randomly, with the stipulation that each stimulus was presented once per block. Data were collected separately for each stimulus-on period. The wavelength presented, number of responses, and latency were recorded for each stimulus-on period, and the total number of responses during stimulus-off periods was recorded for each block. Response rate for each stimulus-on period was also calculated.

RESULTS AND DISCUSSION

Training

Key pecking by all but 1 subject (Subject 8353 from the VI 240-s group) was well maintained following the transition from the FR 1 to the VI schedule. For these subjects, response rates increased across sessions, and the obtained rate of reinforcement approximately equaled the programmed reinforcement rate during all sessions of training. Subject 8353 pecked at a very low rate during the first several sessions of VI training (approximately 0 to 2 responses per minute), and the reinforcement rate for these sessions varied from 0 to 0.05 reinforcers per minute. During the remaining two sessions of training, response rates increased, and reinforcement rate was 0.25 reinforcers per minute, the programmed rate of reinforcement. Another subject in the VI 240-s group (Subject 3530) responded at a lower rate than did any of the other subjects (about 5 responses per minute) except Subject 8353 at the beginning of training, and its rate of reinforcement varied from 0.16 to 0.24 reinforcers per minute.

Response rates during the last session of training were highest for the VI 30-s subjects ($M = 50.2$ responses per minute). Average response rates for the VI 120-s and VI 240-s

groups were 31.9 and 18.0 responses per minute, respectively. Response rates during the short training period that immediately preceded the generalization test were similar to response rates during the last session of training. Average rates were 55.6, 33.8, and 25.7 responses per minute for the VI 30-s, VI 120-s, and VI 240-s subjects, respectively.

Absolute and Relative Generalization

The upper panel of Figure 2 shows that subjects trained with the VI 30-s schedule emitted more responses in the presence of the stimulus used in training than did subjects in the other two groups, which emitted a similar number of responses in the presence of this stimulus. (Note that bars around points, which represent standard errors, overlap for these two groups.) Moreover, the absolute generalization gradient for the VI 30-s group was steeper than the gradients for the VI 120-s and VI 240-s groups. However, the gradients of average relative generalization (lower panel) were similar for the three groups of subjects. The main difference in amount of relative generalization among the groups was in the relative generalization to the stimulus presumed to be most similar to the training stimulus (517 nm). Relative generalization to 517 nm and 538 nm was greater for the VI 120-s group, and error bars do not overlap with the other groups of subjects at the 517- and 538-nm stimuli. (See the Appendix for results of statistical tests.) This difference in extent of generalization to the two stimuli most similar to the training stimulus, however, does not reflect a relation similar to the one reported by Hearst et al. (1964). If that relation had been replicated in the present study, the VI 240-s rather than the VI 120-s subjects would show the most relative generalization. Relative generalization to the other test stimuli was similar for all groups.

Absolute and relative generalization gradients for the VI 240-s subjects in the present study were steeper than those obtained by Hearst et al. (1964) and were similar to those obtained by Haber and Kalish (1963; see Figure 1), who also tested for generalization along the wavelength dimension. The relative generalization gradient for VI 240-s subjects obtained by Hearst et al. was flat; the gradients for VI 240-s subjects in the present study

and in the study by Haber and Kalish were steep.

Another difference in results of the two experiments is in the number of responses emitted in the presence of stimuli presumed to be the most different from the training stimulus, that is, the stimuli at the ends of the continua. Whereas, on average, approximately 150 responses were emitted by individual pigeons in the presence of stimuli at the ends of the line-tilt continuum in the Hearst et al. study, almost none (0 to 17 total responses per pigeon) were emitted in the presence of stimuli at the end of the wavelength continuum in the present study. It may be argued that this comparison is not a fair one given that in the present procedure subjects were trained with stimuli whose values were located on only one side of the wavelength continuum relative to the value of the training stimulus, whereas Hearst et al. tested their subjects with stimuli whose values were located on either side of the line-tilt continuum relative to the location of the value of the training stimulus. In the present study, therefore, the most extreme test stimulus was the most distant of eight stimuli, whereas in the Hearst et al. study the most different test stimulus was separated from the training stimulus by only three intervening test stimuli. However, if one considers only the data for the training stimulus and the four stimuli closest to the training stimulus in the present study, the above description still holds. That is, very few responses occurred to a test stimulus that was only three stimuli removed from the training stimulus. Of course, wavelength and line orientation are different stimulus dimensions and may be scaled very differently. This issue will be addressed in Experiment 2.

The shapes of the gradients of average absolute and relative generalization were representative of the gradients for individual subjects. Individual-subject data for absolute generalization are presented in Figure 3. Absolute and relative (data not shown) generalization gradients for individual subjects were relatively steep, and visual inspection of these graphs does not show any obvious differences in gradient shape among groups. One difference was in the number of responses in the presence of the stimulus closest to the training stimulus on the wavelength continuum (517 nm). Subjects in the VI 120-

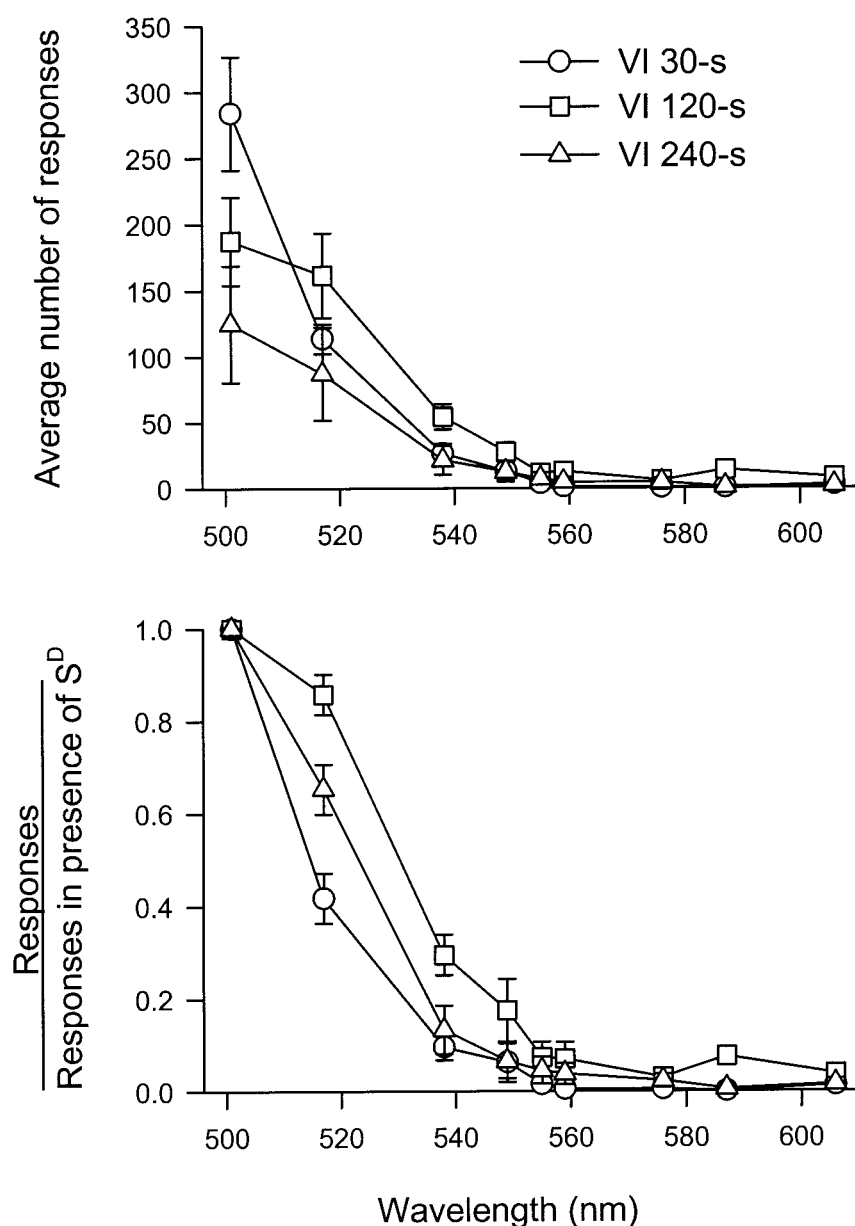


Fig. 2. Gradients of average absolute (upper panel) and relative (lower panel) generalization for subjects trained with a VI 30-s (circles), a VI 120-s (squares), or a VI 240-s (triangles) schedule of reinforcement in the presence of a 501-nm light. Absolute generalization (upper panel) refers to the total number of responses emitted in the presence of each test stimulus as a function of wavelength of the stimulus in nanometers. Relative generalization (lower panel) refers to the total number of responses emitted in the presence of each test stimulus expressed as a proportion of the number of responses in the presence of the training stimulus (discriminative stimulus, or S^D). Bars around points represent standard errors.

s group typically responded more in the presence of this stimulus than did subjects in the other two groups. Overall, however, the shapes of the generalization gradients were

remarkably similar across individual subjects, regardless of their training history.

Subjects in the VI 30-s and VI 120-s groups emitted a similar average number of re-

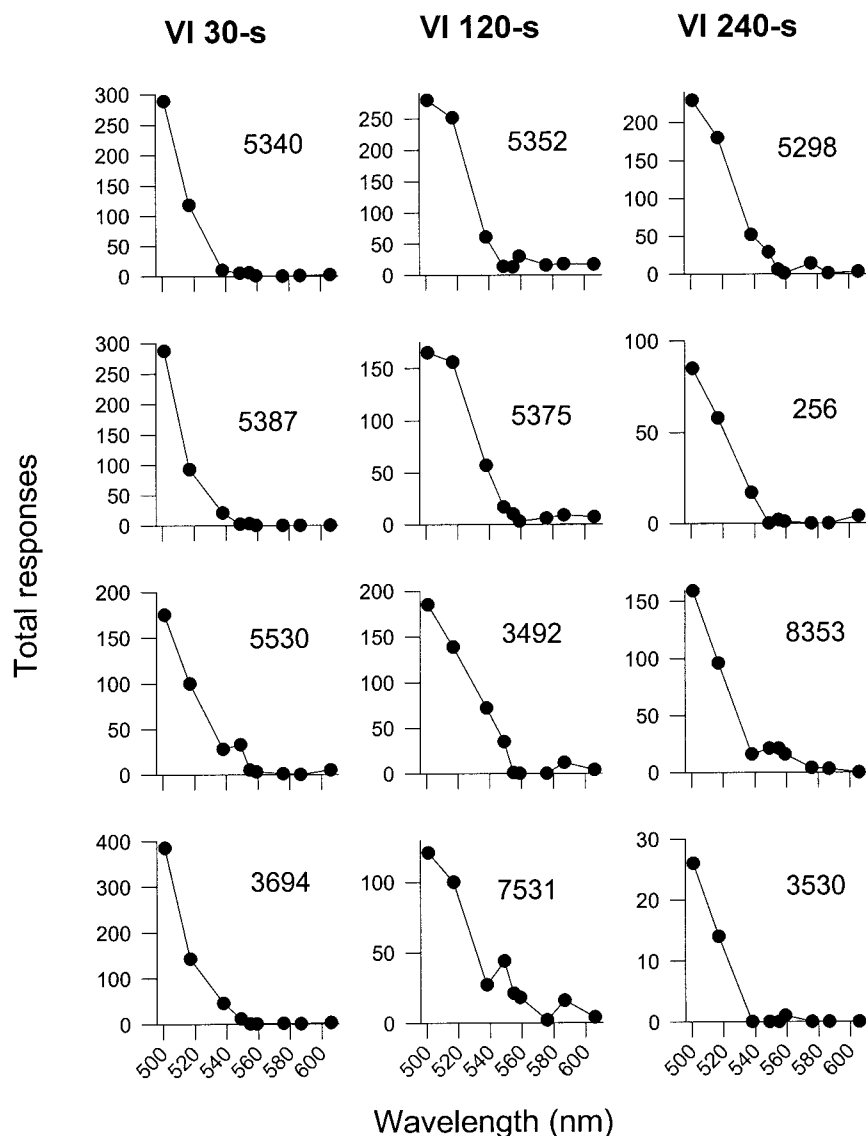


Fig. 3. Gradients of absolute generalization for individual subjects trained with a VI 30-s (left panels), a VI 120-s (center panels), or a VI 240-s (right panels) schedule of reinforcement in the presence of a 501-nm light. See Figure 2 for definition of absolute generalization.

sponses during the generalization test (VI 30 s: average, 445; range, 350 to 594; VI 120 s: average, 483; range, 353 to 699), whereas subjects in the VI 240-s group emitted a smaller average number of responses (average, 265; range, 41 to 515). Although there appeared to be a trend toward fewer responses in the VI 240-s group than in the other groups, the range of response totals for this group overlaps with the ranges for the other two groups,

indicating that this difference was not reliable across subjects in the same group. Hearst et al. (1964) observed no statistically significant differences in the total number of responses emitted during the generalization test across groups. However, because all subjects in their study responded to a similar extent in the presence of stimuli that were not present during training, and the difference in gradient shape was mainly due to an increased num-

ber of responses in the presence of the training stimulus for the VI 30-s and VI 60-s groups, there must have been a trend toward a larger total number of test responses by these subjects.

In the present study the peaks of all gradients were located above the value of the training stimulus along the wavelength continuum, and all gradients showed orderly decrements in responding as a function of distance from the training stimulus. Subjects responded very little in the presence of stimuli that were distant from the training stimulus along the wavelength continuum. In the Hearst et al. (1964) study, the peaks of individual gradients did not always occur at the training stimulus. The peak occurred at the training stimulus for 70% of subjects in the VI 30-s group, for 50% of the VI 120-s subjects, and for 42% of the VI 240-s subjects. Thus, control of responding by the training stimulus occurred to a lesser extent than in the present study.

Latency to Respond in the Presence of the Test Stimuli

If responding was under the control of the training stimulus, the average latency (Figure 4) should be short in the presence of the training stimulus and longer as the value of the test stimulus becomes progressively different from the value of the training stimulus (Margolius, 1955; Mednick & Freedman, 1960). By this measure, orderly gradients of generalization were obtained. Average latencies to respond were short when the training stimulus and the stimulus presumed to be most similar were presented and increased with the value of the stimulus along the wavelength continuum. These gradients did not differ systematically for the different groups of subjects and provide more evidence that the extent of generalization was similar following training with different VI schedules.

Generalization gradients across the wavelength dimension obtained in the present study were much steeper than gradients obtained by Hearst et al. (1964) across a line-tilt continuum, and there was no systematic relationship between VI value and the shape of the gradients. Whereas gradients of both absolute and relative generalization were flat in the Hearst et al. study for subjects trained with the VI 240-s schedule, the gradients ob-

tained for VI 240-s subjects in the present study were steep. In addition, whereas approximately 150 responses, on average, were emitted by each pigeon in the VI 240-s group in the presence of each stimulus in the Hearst et al. study, very few responses were emitted in the present study in the presence of stimuli whose values were far from the value of the training stimulus along the dimension of generalization. It may be argued that this comparison is not a fair one, given the difference in stimulus dimension and that all test stimuli were on one side of the training stimulus; therefore, Experiment 2 was conducted in an attempt to replicate the procedure using line tilt as the stimulus dimension.

Haber and Kalish (1963) also obtained steep gradients of absolute generalization across the wavelength continuum for subjects trained with VI 15-s, VI 60-s, or VI 240-s schedules of reinforcement. The gradients obtained by Haber and Kalish (Figure 1) were very similar in shape to the gradients obtained in the present Experiment 1. Haber and Kalish also observed almost no responding in the presence of stimuli that differed most from the training stimulus. The dimension of generalization, therefore, may be a determinant of the shape of generalization gradients, and this variable may interact with the schedule of reinforcement used in training to determine the shape of generalization gradients.

EXPERIMENT 2

No attempt was made in Experiment 1 to equate the discriminability of the stimuli with those used by Hearst et al. (1964); therefore, the failure to replicate the relation reported by Hearst et al. between VI mean interval and extent of generalization could have been due to a difference in discriminability among stimuli used in the two experiments. Another possibility is that the relation is specific to line orientation or, at least, does not occur for wavelength. Experiment 2 was conducted to examine the reliability of the phenomenon by replicating the Hearst et al. procedure more closely using line orientation as the stimulus dimension. Two groups were studied; responding during training was maintained in the presence of a vertical line by either a VI 30-s or a VI 240-s schedule of food

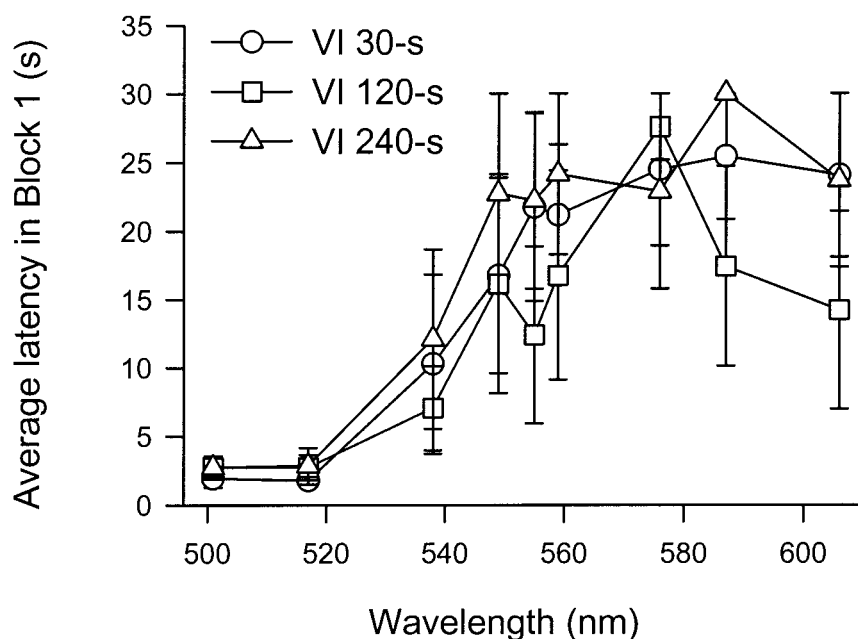


Fig. 4. Average latency to respond in the presence of each test stimulus in the first block of testing for subjects trained with a VI 30-s (circles), a VI 120-s (squares), or a VI 240-s (triangles) schedule of reinforcement in the presence of a 501-nm light. Average latency for each stimulus is plotted as a function of wavelength of the stimulus in nanometers. Bars around points represent standard errors. (A latency of 30 s was recorded if a subject failed to respond during the 30-s stimulus-on period.)

presentation. During generalization testing, different orientations of the line were presented. If the relation reported by Hearst et al. was not replicated in the present study using the same stimulus dimension, we could conclude that the effect may be produced by conditions that were present in the Hearst et al. study but not in the present one.

METHOD

Subjects

Eight adult experimentally naive White Carneau pigeons of indeterminate sex were maintained at 75% of their free-feeding weights. All aspects of housing and care were the same as in Experiment 1.

Apparatus

The same apparatus was used as in Experiment 1, with one modification. The Kodak Wratten filters were removed, and a photographic negative of a picture of eight lines of different orientations was inserted into the projector. Illumination of one lamp behind one line allowed that white line to be projected onto the center of the dark key. The

lines were 0.4 cm wide and crossed almost the entire key. The nominal angles of orientation of the lines included vertical (designated 0°) and, measuring the angle of orientation from the vertical, $+22.5^\circ$, $+45^\circ$, $+67.5^\circ$, $+90^\circ$, -22.5° , -45° , -67.5° , and -90° . The stimulus used in training was the vertical line projected on the key. For the purpose of symmetry around the central point of the gradient (i.e., the 0° training stimulus), the data generated in the presence of the horizontal line are presented twice, once on each side of the gradient ($+90^\circ$ and -90°). The line used as the training stimulus was not perfectly vertical. Its actual orientation was about -0.5° from the vertical. The actual angles of orientation of the lines relative to the training stimulus were, as measured with a protractor, 0° (the training stimulus), $+21.5^\circ$, $+52.5^\circ$, $+70.5^\circ$, $+91.5^\circ$, -23.5° , -41.5° , -67.5° , and -88.5° .

Procedure

Preliminary and VI training. The same procedures were used as in Experiment 1, except that the vertical line, rather than the 501-nm light, was projected onto the key during key-

peck shaping, FR 1, and VI training conditions. Adaptation lasted for one 30-min session, and magazine training lasted for one to two sessions, each of which lasted until about 30 min elapsed or approximately 40 to 50 food presentations occurred. Key-peck shaping lasted for one session (between 5 and 20 min until the pigeon pecked the key), and the FR 1 schedule was in effect for 100 reinforcements (two sessions of 50 reinforcements each). Only two groups were studied; one group was trained with a VI 30-s schedule, and the other group responded under a VI 240-s schedule of food presentation. All subjects experienced 10 sessions of VI training, except 1 pigeon in the VI 30-s group (Subject 4415), which experienced 11 sessions. The same response and reinforcement measures were collected as in Experiment 1.

Generalization testing. Testing was conducted in the same way as in Experiment 1. Training conditions were in effect for the first 10 min of the test session. During this time the vertical line was projected on the key, and the schedule of reinforcement was in effect. After this preliminary period, testing was conducted in extinction with different line orientations as the test stimuli. Eight orientations of the line were used as stimuli; therefore, each of the 10 blocks consisted of eight stimulus presentations, determined as were stimulus presentations in Experiment 1. The same response and reinforcement measures were collected as in Experiment 1.

RESULTS AND DISCUSSION

Training

Responding was maintained following the transition from the FR 1 to the VI schedule. Response rates increased across the first few or several sessions and then stabilized for all subjects. The average response rate for the last session of training was 50.4 responses per minute for the VI 30-s group and 25.5 responses per minute for the VI 240-s group. Response rates during the preliminary period of testing were very similar to rates during the last session of training. Average response rates during the preliminary period of the test session were 52.5 responses per minute for the VI 30-s group and 29.4 responses per minute for subjects trained with the VI 240-s schedule. Obtained reinforcement rates ap-

proximated programmed reinforcement rates by the third session of training for 7 subjects.

Absolute and Relative Generalization

The plots in the upper panel of Figure 5 show that subjects trained with the VI 30-s schedule typically emitted a greater number of responses during the generalization test than did subjects trained with the VI 120-s schedule. Although the absolute generalization gradient for the VI 30-s subjects was displaced upward relative to the gradient for the VI 240-s subjects, the shapes of the gradients (i.e., the slopes of the gradients on either side of the value of the training stimulus) were similar. To facilitate comparison of the two gradients by normalizing responding, gradients of relative generalization are shown for the two groups of subjects in the lower panel of Figure 5. The right halves of the gradients were virtually identical for the two groups, whereas the left half of the gradient for subjects trained with the VI 240-s schedule was somewhat steeper than that for the VI 30-s subjects, a result that is opposite of the relation reported by Hearst et al. (1964). (See the Appendix for results of statistical tests.)

The gradients shown in Figure 5 are similar in shape to those from Experiment 1, in which wavelength of light was the stimulus dimension (see Figure 2), although a direct comparison is impossible given the difference in dimension of generalization. Average gradients of absolute and relative generalization obtained in the present study were very steep compared to those obtained by Hearst et al. (1964), regardless of the dimension of generalization tested. Whereas the gradients obtained by Hearst et al. were flat for the VI 240-s subjects, those obtained in the present study for subjects trained with a VI mean interval of 240 s were not, even when the dimension of generalization was line tilt and the spacing of stimuli was almost identical to that in the study by Hearst et al.

Another difference in results is that in the present study, only 0 to 58 responses were emitted in the presence of stimuli at the ends of the continuum (i.e., 91.5° or -88.5° , -67.5° , and 70.5° from the training stimulus), whereas in the Hearst et al. (1964) study, pigeons emitted about 150 responses, on average, in the presence of stimuli at the ends of

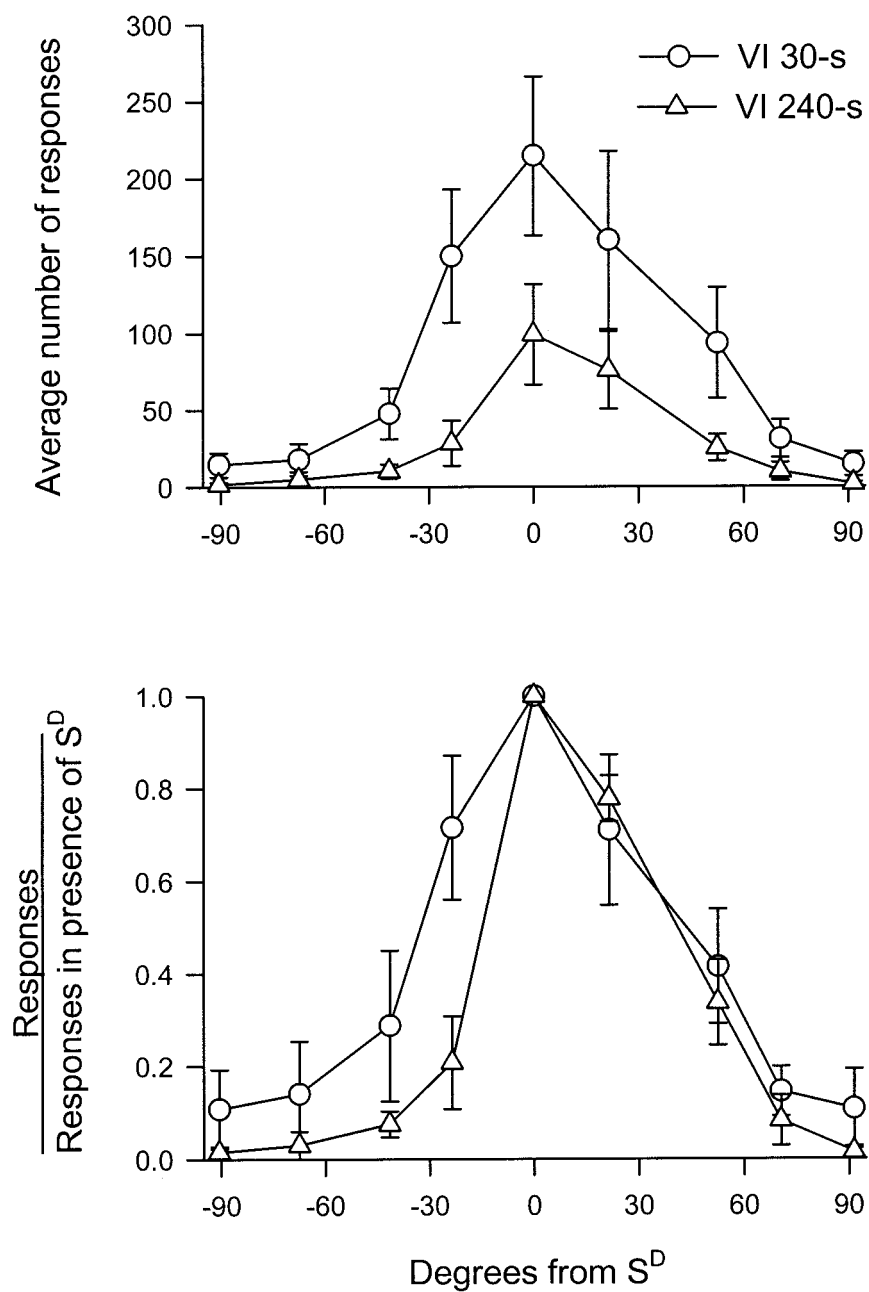


Fig. 5. Gradients of average absolute (upper panel) and relative (lower panel) generalization for subjects trained with a VI 30-s (circles) or a VI 240-s (triangles) schedule of reinforcement in the presence of a vertical line. Absolute generalization (upper panel) refers to the total number of responses emitted in the presence of each test stimulus as a function of angular degrees from the training stimulus (S^D). Relative generalization (lower panel) refers to the total number of responses emitted in the presence of each test stimulus expressed as a proportion of the number of responses in the presence of the training stimulus. Bars around points represent standard errors.

the continuum (i.e., 90° , -67.5° , and 67.5° from the training stimulus). Other researchers have published gradients of generalization along a line-orientation continuum that show a large number of responses in the presence of stimuli at the ends of the continuum (Hearst & Koresko, 1968; Honig, Boneau, Burstein, & Pennypacker, 1963). Hearst and Koresko, for example, trained different groups of pigeons with a VI 60-s schedule for different numbers of sessions according to the procedure used by Hearst et al. (1964). They constructed absolute generalization gradients by plotting the total number of responses emitted in the presence of the test stimuli by all subjects in a group. The number of responses emitted in the presence of stimuli whose values were furthest from the training stimulus on the line-tilt continuum varied from approximately 400 to 1,200 responses (an average of 50 to 150 responses per pigeon in 50 min of testing or 37.5 min in the presence of the test stimuli).

Average generalization gradients were representative of individual-subject gradients, which are shown in Figure 6 for absolute generalization for all subjects. Absolute generalization gradients show that 3 of the 4 subjects trained with the VI 30-s schedule responded more during the generalization test than did subjects trained with the VI 240-s schedule. The average number of responses emitted in the test was 728 and 255 responses for the VI 30-s and VI 240-s groups, respectively. Individual-subject response totals ranged from 255 to 1,092 responses for the VI 30-s group and from 25 to 443 responses for the VI 240-s group. The shapes of individual gradients of both absolute and relative generalization (data not shown) were similar. Subject 4415 (from the VI 30-s group) emitted more responses in the presence of stimuli at the ends of the continuum than did the other subjects, and the peak of this subject's gradient did not occur at the value of the training stimulus. In general, absolute and relative generalization gradients were similar for the two groups of subjects, except that the left side of the gradients was steeper for the VI 240-s subjects than for subjects trained with the VI 30-s schedule, a difference that is largely attributable to the data from Subject 4415. (This difference is also noticeable in the gradients

for average generalization shown in Figure 5.)

Latency to Respond in the Presence of the Test Stimuli

Figure 7 shows average latency to respond in the first block of testing in the presence of each stimulus. In general, orderly gradients of generalization occurred for both groups of subjects; average latency in the presence of the training stimulus was short, and latency increased as the number of degrees between training and test stimulus increased. The right halves of the generalization gradients for latency to respond were virtually identical for the two groups of subjects, whereas the left halves indicate that, on average, subjects trained with the VI 30-s schedule began to peck the key more quickly than subjects trained with the VI 240-s schedule when lines were presented whose orientations were -23.5° , -41.5° , and -67.5° from the orientation of the line used in training. This effect was due mainly to the short latencies for Subject 4415 in the presence of these stimuli. Gradients for latency for the other VI 30-s subjects were similar to those for subjects in the VI 240-s group. The generalization gradient for average latency was steeper for the VI 240-s subjects than for the VI 30-s subjects. This characterization of generalization, then, is very similar to that shown in Figure 5. The relation reported by Hearst et al. (1964) between VI value and extent of generalization was not replicated in the present study, and the small differences that were observed reflect a relation opposite of that which would be predicted by the Hearst et al. findings.

The results from Experiment 2 are consistent with those from Experiment 1; these results show that the inverse relation between VI mean interval and steepness of gradient slope reported by Hearst et al. (1964) was not replicated in the present study, regardless of the stimulus dimension studied. Generalization gradients were steep following training with either a VI 30-s or a VI 240-s schedule of reinforcement, and this result occurred with both wavelength and line orientation. It appears, then, that under the conditions of the present experiments, the schedule of reinforcement used in single-stimulus training has little effect on the extent of generalization. In addition, because the total number

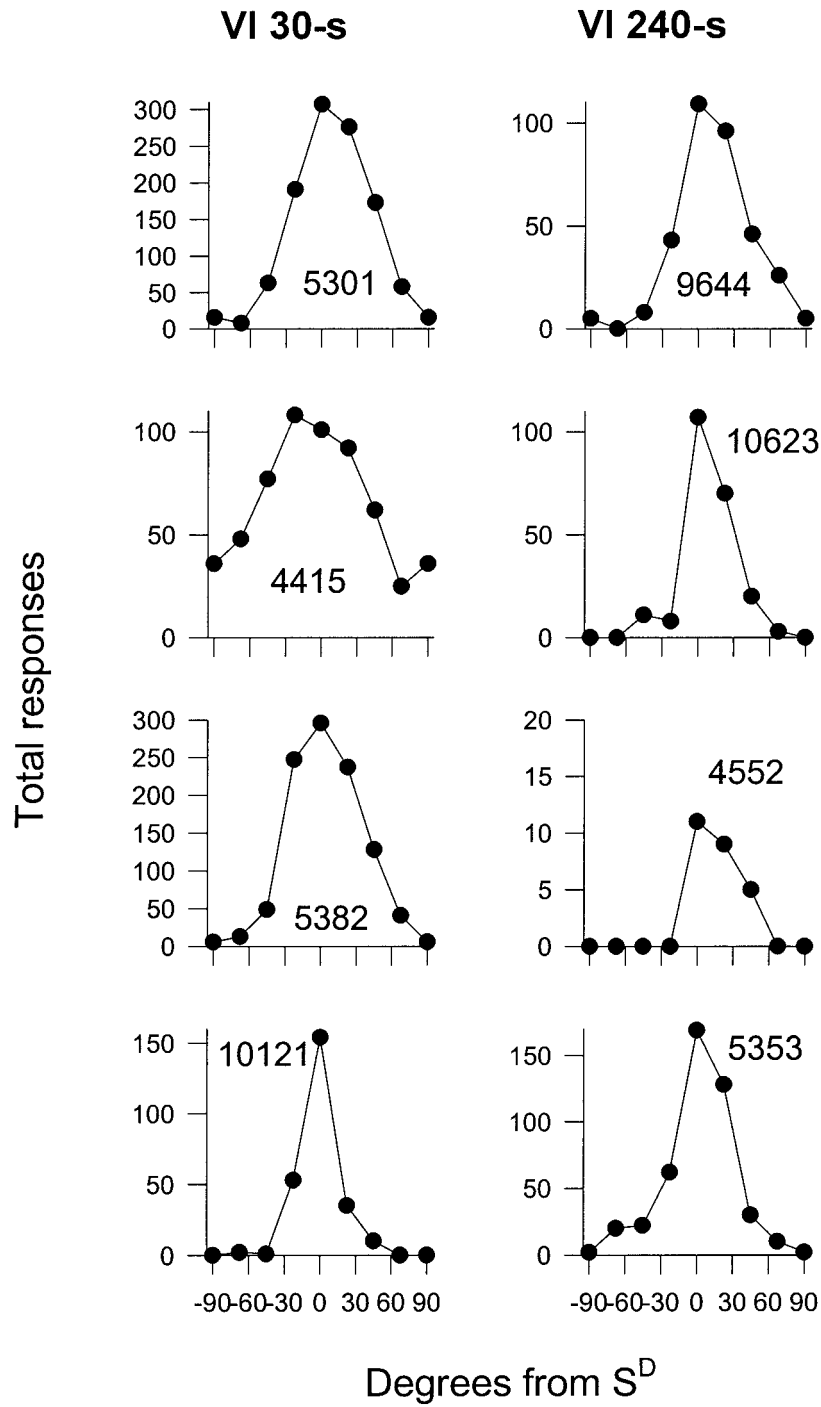


Fig. 6. Gradients of absolute generalization for individual subjects trained with a VI 30-s (left panels) or a VI 240-s (right panels) schedule of reinforcement in the presence of a vertical line. See Figure 5 for definition of absolute generalization.

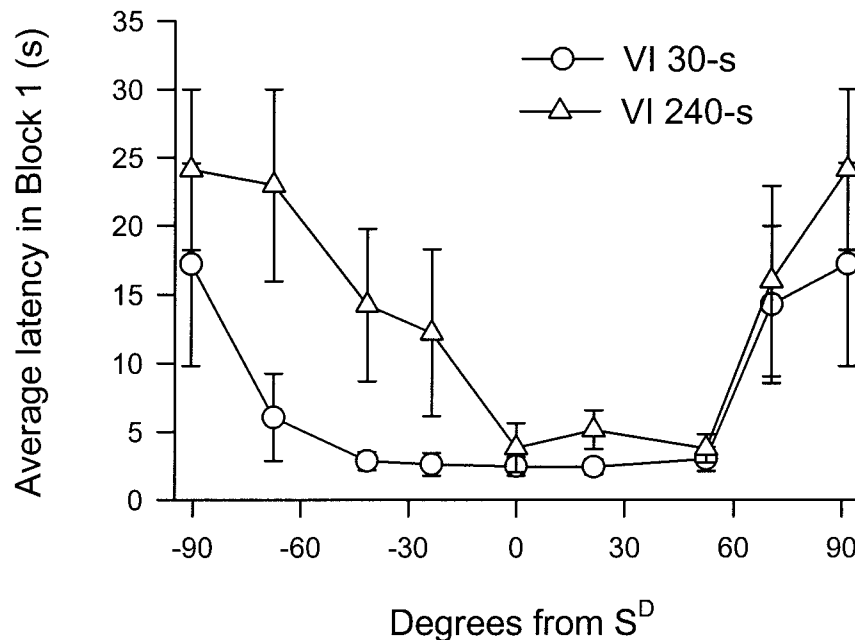


Fig. 7. Average latency to respond in the presence of each test stimulus in the first block of testing for subjects trained with a VI 30-s (circles) or a VI 240-s (triangles) schedule of reinforcement in the presence of a vertical line. Average latency for each stimulus is plotted as a function of angular degrees from the training stimulus (S^D). Bars around points represent standard errors. (A latency of 30 s was recorded if a subject failed to respond during the 30-s stimulus-on period.)

of reinforcers obtained by subjects trained with different VI schedules differed but the gradients were similar, the number of reinforcers obtained during single-stimulus training may not be an important determinant of the shape of generalization gradients, at least under the present circumstances (i.e., when generalization testing follows 10 sessions of training via the present procedure). One difference that was observed in Experiments 1 and 2 was the tendency for subjects in the VI 30-s groups to respond more frequently during the generalization test than subjects in the VI 240-s groups. This difference resulted in the upward displacement of the absolute generalization gradient for the VI 30-s subjects relative to the gradient for the VI 240-s subjects. It may be that the number of reinforcers (or the rate of reinforcers) obtained during training affects the absolute amount of responding during testing, but not the extent of relative generalization.

EXPERIMENT 3

The original purpose of the present set of experiments was to examine whether the to-

tal number of reinforcers earned during training was the variable responsible for the greater extent of generalization following training with longer VI schedules than following training with shorter VI schedules in the study by Hearst et al. (1964). This relation was not replicated in the present set of experiments. Experiment 3, however, was conducted to test whether the amount of training might be a determinant of the extent of generalization along the wavelength dimension.

The present Experiments 1 and 2 utilized a common procedure for conducting experiments on generalization following single-stimulus training. This procedure includes training subjects to respond in the presence of a particular stimulus for a specific number of training sessions (usually 10 to 11); then testing for generalization occurs in a single session (e.g., Guttman & Kalish, 1956; Harrison, 1991; Rilling, 1977; Terrace, 1966). In many operant conditioning experiments, subjects are trained for a minimal number of sessions (e.g., 30) until some measure of responding (e.g., response rate, latency) is stable; that is, the level does not change

systematically from session to session, and the variability of responding from session to session is minimal. Then the effects of independent variables are assessed (Sidman, 1960). In Experiment 3 two groups of 4 pigeons each were trained to peck a key under conditions identical to those for pigeons in the VI 30-s and VI 240-s groups in Experiment 1, with one modification. These subjects were trained until their response rates became stable according to a stability criterion described by Perone (1991). Then generalization testing was conducted. Data from these pigeons were compared with data from the pigeons in the VI 30-s and VI 240-s groups from Experiment 1 to see if their more prolonged training would produce generalization gradients that differed from those of subjects that experienced only 10 sessions of training.

According to Dinsmoor (1995a), gradients of stimulus generalization become steeper with more prolonged training. For example, Hearst and Koresko (1968) replicated the procedure used by Hearst et al. (1964) for subjects trained with a VI 60-s schedule of food presentation. Four groups of pigeons experienced 2, 4, 7, or 14 sessions of training with a VI 60-s schedule of reinforcement in the presence of a vertical line. Generalization testing was conducted in extinction. The authors found that the slopes of both absolute and relative generalization gradients became steeper with increased single-stimulus training, a result that is consistent with the hypothesis that the number of reinforcers obtained during training may have been responsible for the steeper slopes obtained by Hearst et al. when the VI mean interval was shorter. This result is also consistent with the notion that generalization gradients become steeper with more prolonged VI training. That is, gradients of absolute and relative generalization were steeper for subjects that experienced more training than for subjects that experienced less training with the same schedule of reinforcement. Farthing and Hearst (1968) also found that gradients of inhibition were steeper following 4, 8, or 16 sessions than following one or two sessions of training.

Other researchers, however, have reported that generalization gradients become flatter with more prolonged training (Hearst & Koresko, 1968; Margolius, 1955; Mednick &

Freedman, 1960; Olson & King, 1962). Olson and King compared generalization gradients along a luminosity continuum for pigeons trained for 2, 5, 10, or 20 sessions with a VI 60-s schedule according to the procedure used by Hearst et al. (1964). Gradients of average relative generalization were steepest for the subjects trained for five sessions. The gradient for subjects trained for 10 sessions was similar to that for subjects trained for two sessions, and the relative generalization gradient for the 20-session group was the flattest. These results are consistent with the possibility that generalization gradients become steeper as training continues and then become flatter with more prolonged VI training.

This assortment of results appears to indicate that the steepness of gradients of stimulus generalization is a function of the amount of training, up to some maximum number of sessions (Hearst & Koresko, 1968) or reinforcers (Margolius, 1955). More extensive training with a VI schedule of reinforcement may result in a flattening of the gradient (Olson & King, 1962). Experiment 3 was conducted to examine the relation between amount of training with a VI 30-s or VI 240-s schedule in the presence of a particular wavelength of light and the extent of generalization to stimuli that differ along the wavelength dimension. The questions addressed by this experiment were: (a) Does prolonged training influence the extent of generalization? (b) Do generalization gradients differ for subjects trained to stability compared to those trained for the typical 10 to 11 sessions?

METHOD

Subjects and Apparatus

Eight adult experimentally naive White Carneau pigeons of indeterminate sex were maintained at 75% of their free-feeding weights. All aspects of housing and care were the same as in Experiment 1.

The apparatus was identical to that used in Experiment 1.

Procedure

Preliminary and VI training. The same procedures were used as in Experiment 1. Adaptation lasted for one 20- to 30-min session, and magazine training lasted for one to two

Table 1

Average number of responses per minute (with ranges in parentheses) during the 10th session of training for subjects trained for 10 sessions (Experiment 1) and during the 10th and last sessions of training for subjects trained until their response rates stabilized (>30 sessions).

Training amount	VI 30 s		VI 240 s	
	Session 10	Last session	Session 10	Last session
10 sessions	50.2 (42.0–62.3)		18.0 (4.5–24.4)	
>30 sessions	37.9 (19.8–69.1)	48.2 (34.5–75.8)	20.5 (4.0–27.4)	36.0 (27.2–45.2)

sessions of approximately 40 food presentations or 30 min.

Key-peck shaping lasted for one session, and the FR 1 schedule was in effect for 100 to 150 reinforcements (50 reinforcements per session). Two groups were studied; the schedule in effect was VI 30 s or VI 240 s for different groups of subjects, and sessions were conducted until stability criteria were met. These stability criteria have been described by Perone (1991) and are based on response rates from nine consecutive sessions. Nine consecutive sessions were divided into groups of three, and the mean response rate for each group of three sessions was calculated. If these means did not show a decreasing or increasing trend, and if they did not differ from the overall mean response rate for all nine sessions by more than 10%, the response rates were considered stable. When these stability criteria were met, testing began. The same response and reinforcement measures were collected as in Experiment 1.

Generalization testing. Testing was conducted in the same way as in Experiment 1. The same response and reinforcement measures were collected as in Experiment 1.

RESULTS AND DISCUSSION

Training

Responding was maintained following the transition from the FR 1 to the VI schedule for all subjects. Response rates for all subjects whose response rates stabilized increased gradually across training sessions then stabilized. Response rates for subjects trained with the VI 30-s schedule stabilized after 33 (Subject 8915), 31 (Subject 2874), 36 (Subject 2949), or 35 (Subject 2944) sessions. For subjects trained with the VI 240-s schedule, response rates stabilized after 32 (Subject 9630), 40 (Subject 2255), 40 (Subject 10575),

or 57 (Subject 1352) sessions. With one exception, subjects trained with the VI 240-s schedule required more sessions for their response rates to become stable.

Table 1 shows average response rates during the last session of training for subjects trained for 10 sessions and rates during the 10th and last sessions of training for subjects trained to stability. The average response rate during the last session of training for the VI 30-s subjects trained to stability was similar to the average rate during the 10th session for the VI 30-s subjects from Experiment 1. For the VI 240-s subjects trained to stability, average response rate during the last session of training was higher than the rate for subjects from Experiment 1. For all subjects trained to stability, response rates were lower during the 10th session of training than at the end of training. Response rates during the preliminary period of the test session correlated well with rates during the last session of training for these subjects (52.2 and 34.3 responses per minute for the VI 30-s and VI 240-s subjects, respectively). Reinforcement rates were similar to the programmed rates of reinforcement for all subjects trained to stability.

Absolute and Relative Generalization

Figure 8 shows that absolute and relative generalization gradients were virtually identical for both groups of subjects trained with the VI 30-s schedule (left panels). Among the VI 240-s subjects, however, those trained to stability responded more during testing than did the VI 240-s subjects from Experiment 1 (upper right panel). That is, the gradient was displaced upward relative to the gradient for subjects trained for 10 sessions. (Note that error bars do not overlap except for stimuli whose values are far from the training stimulus on the wavelength continuum.) The ex-

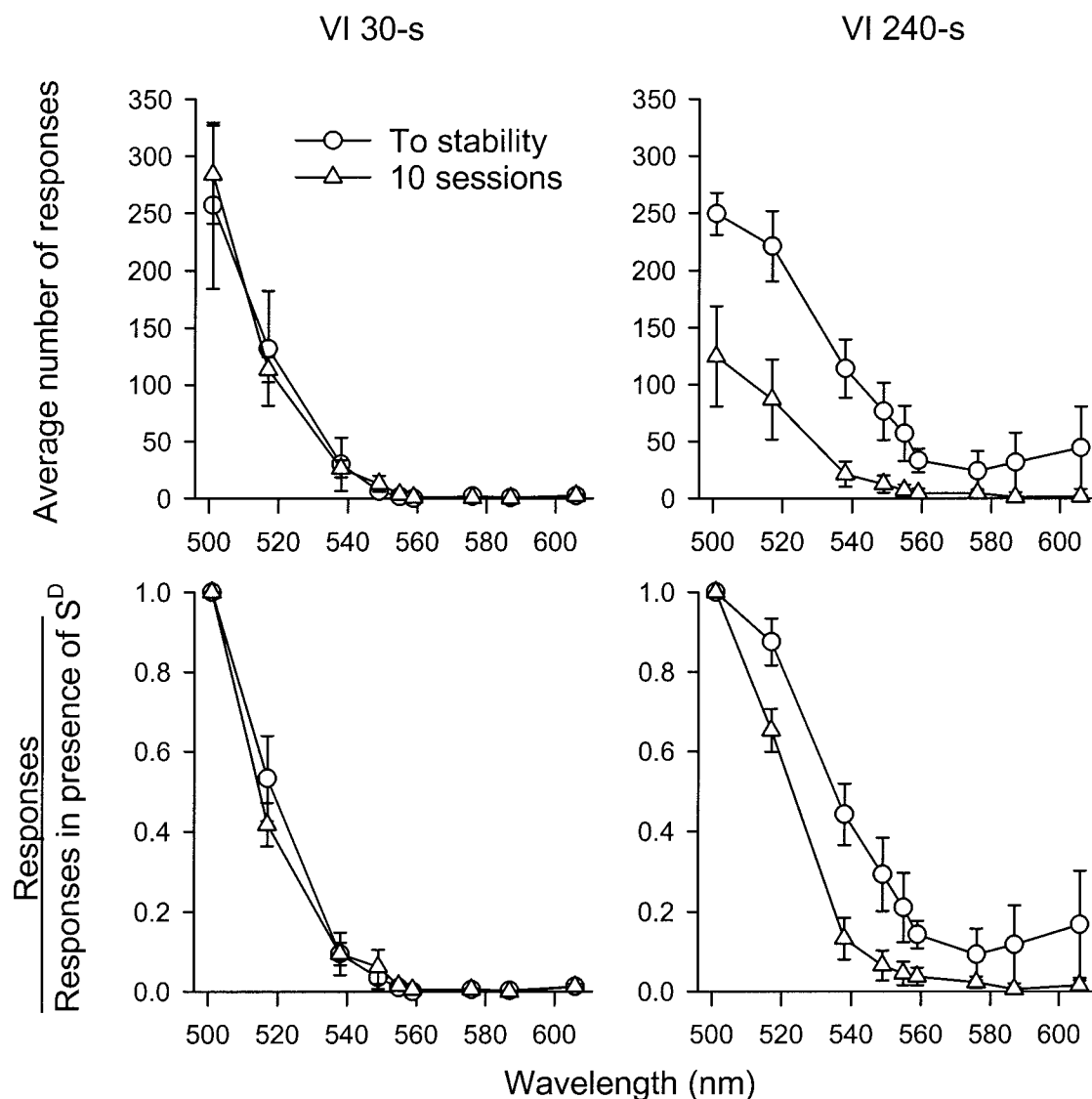


Fig. 8. Gradients of average absolute (upper panels) and relative (lower panels) generalization for subjects trained with a VI 30-s (left panels) or a VI 240-s (right panels) schedule of reinforcement in the presence of a 501-nm light. Subjects were trained for 10 sessions (triangles) or until their response rates were stable (circles). Absolute generalization (upper panels) refers to the total number of responses emitted in the presence of each test stimulus as a function of wavelength of the stimulus in nanometers. Relative generalization (lower panels) refers to the total number of responses emitted in the presence of each test stimulus expressed as a proportion of the number of responses in the presence of the training stimulus. Bars around points represent standard errors.

tent of relative generalization (lower right panel) also was greater for the VI 240-s subjects that experienced more training. (See the Appendix for results of statistical tests.)

Gradients of absolute generalization are shown for individual subjects in Figures 9 and 10. The average gradients usually were rep-

resentative of gradients for individual subjects, except for Subject 10575 from the VI 240-s group. Absolute generalization gradients were similar in shape for all subjects trained with the VI 30-s schedule (Figure 9). Figure 10 shows that 3 of the 4 VI 240-s subjects (all but Subject 2255) that experienced more

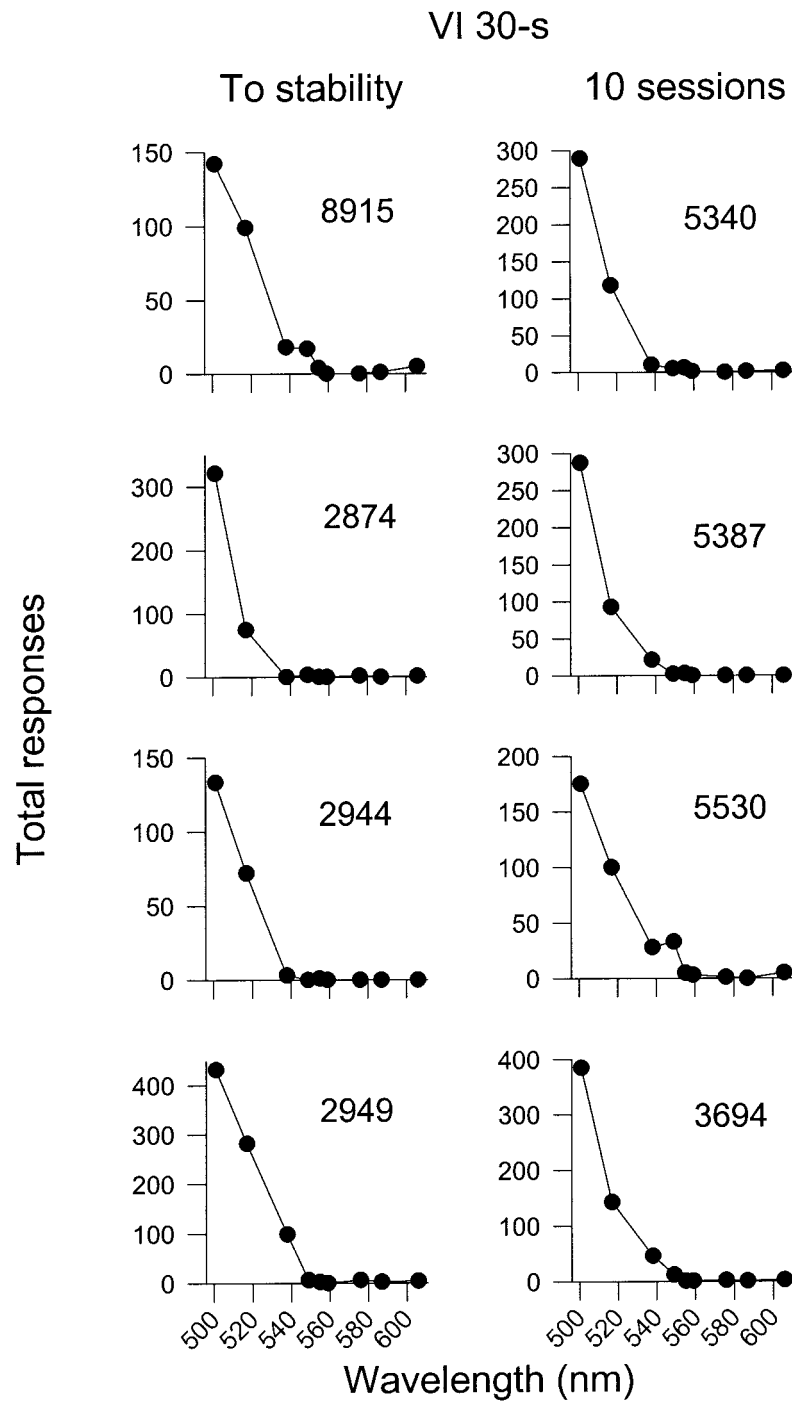


Fig. 9. Gradients of absolute generalization for individual subjects trained with a VI 30-s schedule of reinforcement in the presence of a 501-nm light until their response rates were stable (left panels) or for 10 sessions (right panels). See Figure 8 for definition of absolute generalization.

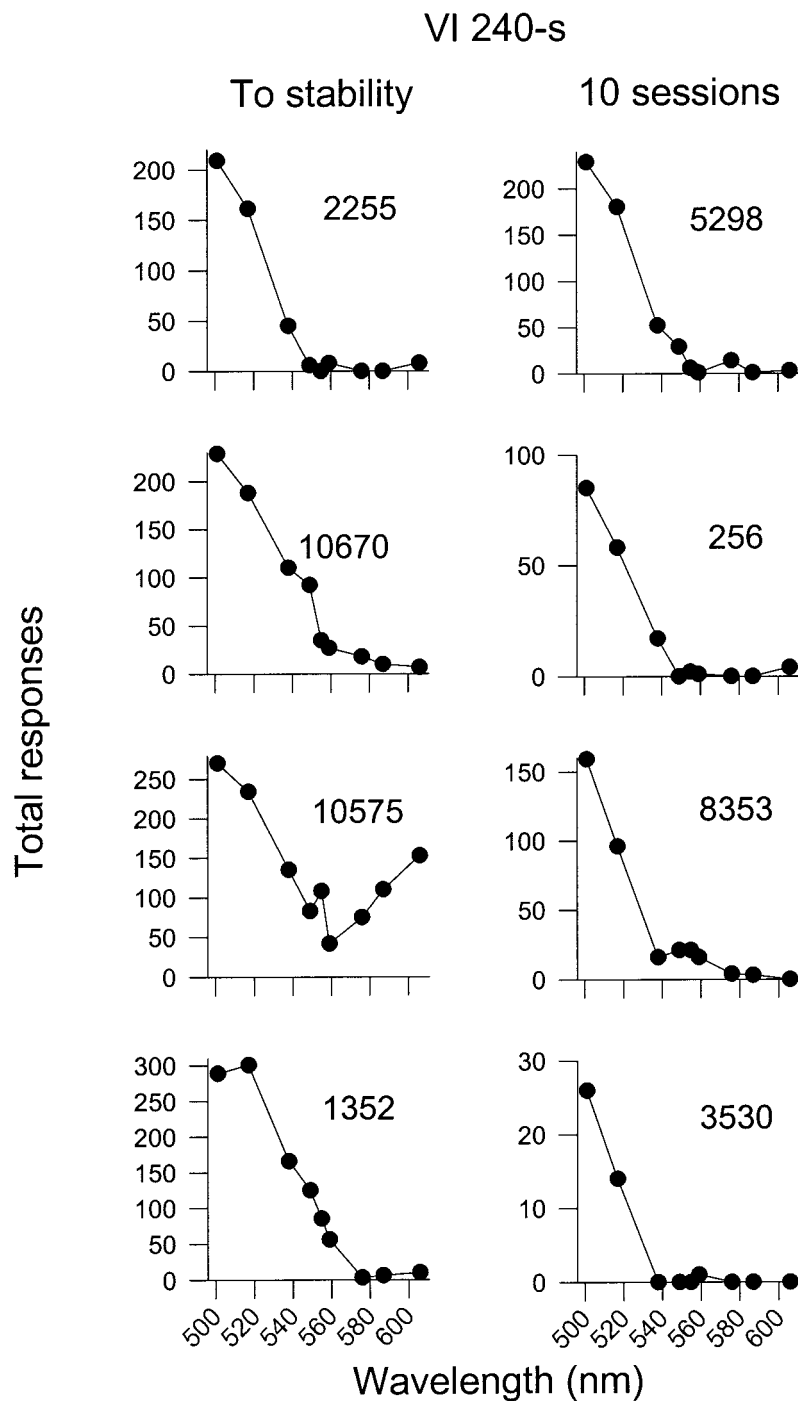


Fig. 10. Gradients of absolute generalization for individual subjects trained with a VI 240-s schedule of reinforcement in the presence of a 501-nm light until their response rates were stable (left panels) or for 10 sessions (right panels). See Figure 8 for definition of absolute generalization.

than 10 sessions of training (left panels) responded more (note y-axis values) during the test than did subjects trained for 10 sessions (right panels). Subject 2255 emitted fewer responses than the other subjects trained to stability with the VI 240-s schedule, and the generalization gradient for this subject was very similar to the gradients for the VI 240-s subjects from Experiment 1. Responding by the other 3 subjects in the stability group generalized more than the VI 240-s subjects trained for 10 sessions. The absolute generalization gradient for Subject 10575 was unusual, however, in that this subject responded more to stimuli far from the value of the training stimulus on the wavelength continuum than it did to stimuli in the middle of the continuum nearer the value of the training stimulus. For subjects trained with a VI 30-s schedule, then, increasing the number of training sessions had no effect on the extent of absolute or relative generalization; however, prolonged training with a VI 240-s schedule resulted in more responses being emitted in the test and in a greater extent of both absolute and relative generalization. Other researchers have reported a flattening of the gradient when training with a VI schedule occurs for 20 sessions or more (Olson & King, 1962). What remains to be explained is why prolonged training would result in a flattening of the gradient for subjects trained with a VI 240-s but not a VI 30-s schedule of reinforcement.

Latency to Respond in the Presence of the Test Stimuli

Figure 11 shows orderly gradients of generalization for the average latency to respond. That is, the latency to respond in the presence of the training stimulus was short, and average latency increased as the distance between the value of the training stimulus and the value of the test stimulus along the dimension of generalization increased. The gradients were almost identical for the four groups of subjects (except for one outlying data point at the 587-nm stimulus for the VI 240-s subjects trained to stability). Average latencies to respond were similar, and error bars overlap at all but one (587 nm) stimulus value. By this measure of generalization, then, subjects that experienced 10 sessions of single-stimulus training with a VI 30-s or VI 240-s schedule generalized to an extent sim-

ilar to subjects trained until their response rates became stable.

For the first time in this series of studies, the latency data resulted in a different characterization of generalization than did gradients of absolute and relative generalization, at least for the VI 240-s subjects. Absolute and relative generalization gradients for subjects trained for 10 sessions were steeper, and the absolute generalization gradient was displaced downward compared to the gradient for subjects trained to stability; however, the gradients for latency to respond in the first block were similar for the two groups. These results suggest that absolute and relative generalization gradients during the first block of the session might be similar, but that responding by subjects trained for 10 sessions might extinguish faster than responding by subjects trained to stability, especially in the presence of stimuli whose values were far from the value of the training stimulus on the wavelength continuum. This was not the case, however; neither latency nor number of test responses varied systematically across blocks for either group (data not shown), and data from the first block were representative of data from the other blocks for both latency and number of responses. This result indicates that latency may be a less sensitive indicator of generalization than absolute or relative response rate in some cases and points to the importance of including more than one dependent variable in studies on stimulus generalization. (The insensitivity of the latency measure may, however, be due to the fact that only one latency could be sampled per stimulus per block for each subject, whereas the number of responses could vary.)

Results from the present experiment suggest that more prolonged training has little effect on the extent of generalization following single-stimulus training with a VI 30-s schedule. However, when subjects were trained with the VI 240-s schedule, 10-session training was associated with fewer responses during the test and a lower level of absolute and relative generalization. A comparison of the lower panels of Figure 8 shows that the extent of relative generalization was similar for both VI 30-s groups and the VI 240-s group that was trained for 10 sessions. A comparison of gradients following training to stability, however, shows that the gradient for the VI 240-s subjects was flatter

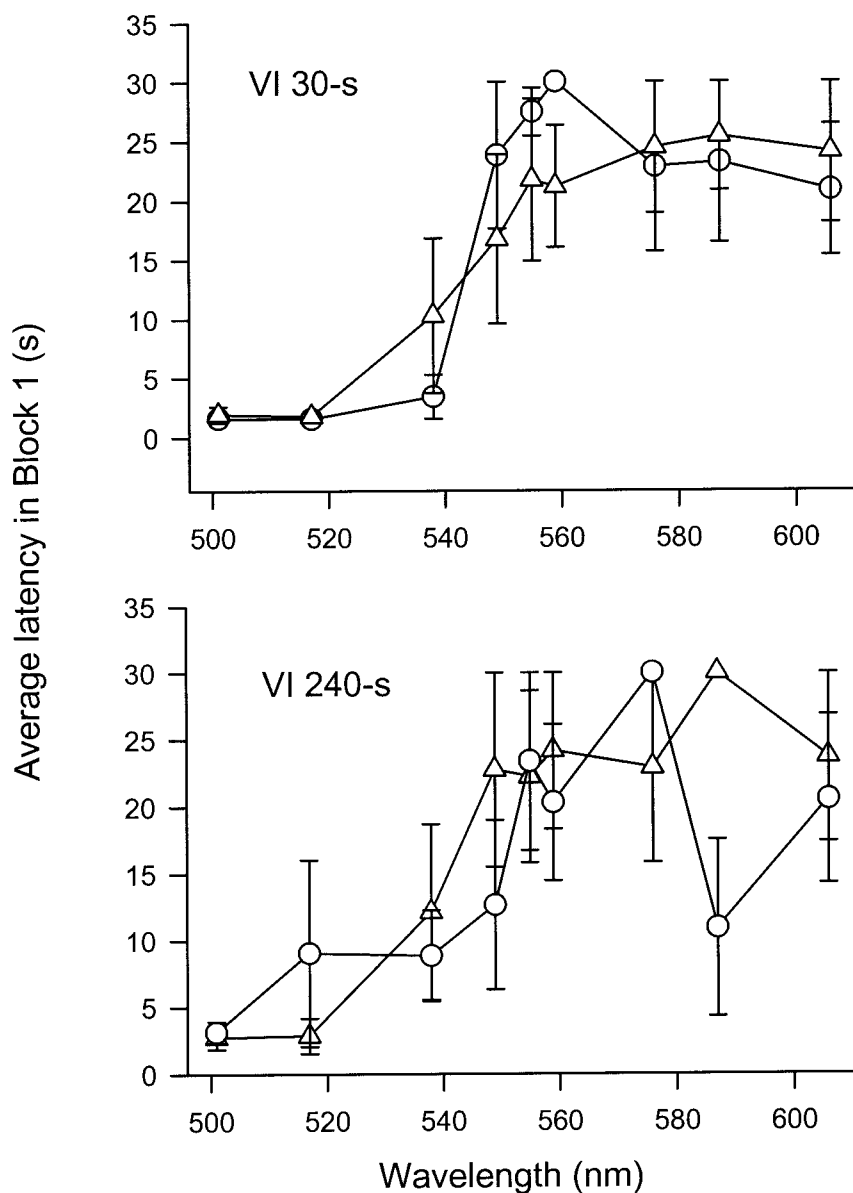


Fig. 11. Average latency to respond in the presence of each test stimulus in the first block of testing for subjects trained with a VI 30-s (upper panel) or a VI 240-s (lower panel) schedule of reinforcement in the presence of a 501-nm light. Subjects were trained for 10 sessions (triangles) or until their response rates were stable (circles). Average latency for each stimulus is plotted as a function of wavelength of the stimulus in nanometers. Bars around points represent standard errors. (A latency of 30 s was recorded if a subject failed to respond during the 30-s stimulus-on period.)

than that for the VI 30-s subjects. Thus, for the first time in the present series of studies, a result consistent with the relation reported by Hearst et al. was obtained. Why this relation was observed only when subjects were trained for

more than 30 sessions remains to be explained. It appears that prolonged training for more than 20 sessions can result in a flattening of the generalization gradient but that the effect is schedule dependent.

GENERAL DISCUSSION

In the present set of experiments, orderly gradients of generalization were obtained following single-stimulus training with a VI schedule of reinforcement. That is, a relatively high number of responses occurred in the presence of the training stimulus, and responding decreased as the difference between the value of the test stimulus and the value of the training stimulus along the dimension of generalization increased. This result occurred when training was conducted with VI 30-s, VI 120-s, or VI 240-s schedules, and when the dimension of generalization was wavelength or line orientation. When training was conducted with a VI 30-s schedule, more prolonged training tended to result in gradients of absolute and relative generalization that were very similar to gradients for subjects trained for only 10 sessions. When training was conducted with a VI 240-s schedule, more prolonged training tended to result in absolute and relative generalization gradients that were flatter than gradients for subjects with only 10 sessions of training; however, when latency to respond in the first block was plotted as a function of stimulus value, gradients for these subjects were similar. In all other cases, gradients of average latency to respond indicated levels of generalization similar to those shown by gradients of absolute and relative generalization.

In keeping with the present findings, other research has shown that rate of reinforcement in training may not be an important determinant of the extent of generalization in testing (e.g., Eckerman, 1969; Haber & Kalish, 1963). The data presented by Haber and Kalish (Figure 1) show that when key pecking by pigeons was maintained by either VI 15-s, VI 60-s, or VI 240-s schedules of food presentation, gradients of generalization were steep. The only apparent difference was in the number of responses in the presence of the training stimulus. Subjects trained with the most frequent reinforcement (the VI 15-s group) responded more in the presence of the training stimulus than did the other subjects. Otherwise, the gradients were similar. In addition, Eckerman showed that the extent of stimulus control following discrimination training (where stimulus control was defined as the ratio of responding in the pres-

ence of S+ to responding in the presence of S-) was equivalent for subjects trained with different probabilities of reinforcement in the presence of S+. Similar levels of stimulus control occurred for all subjects after approximately equal numbers of reinforcer deliveries, indicating that the absolute level of stimulus control did not depend on the rate of reinforcement, as long as subjects had experienced some minimal number of reinforcers in training. Perhaps in the present Experiments 1 and 2, the total number of reinforcers obtained during training was enough to establish equivalent levels of stimulus control following training with different VI schedules. That does not explain, however, why Hearst et al. (1964) found an effect of reinforcement schedule under conditions very similar to those employed in the present study.

It remains, therefore, to be explained why Hearst et al. (1964) observed flat generalization gradients along a line-orientation continuum following 10-session training with a VI 240-s schedule, whereas this result was not obtained in the present study. Dinsmoor (1995b) has suggested that there are two stimulus parameters that influence the level of stimulus control that can be attained. These parameters are stimulus disparity and stimulus salience. Stimulus disparity refers to "the magnitude of the difference in physical units between [the stimuli to be discriminated]" (p. 254). Stimulus salience refers to "the magnitude of the difference between the discriminative stimuli [i.e., the training stimulus] and the background stimulation" (p. 254). This relation may explain the difference in results obtained by Hearst et al. (1964) and those in the present Experiment 2 for subjects trained with a VI 240-s schedule. That is, line stimuli in the present study may have been more salient than lines in the study by Hearst et al. The discrepancy in results of other experiments that have examined stimulus control by line orientation may be explained in a similar way. In addition, the data presented by Haber and Kalish (1963) provide evidence that the VI value used in training is not necessarily a strong determinant of the shape of generalization gradients; rather, the relation reported by Hearst et al. between reinforcement rate and extent of generalization may occur under a limited set

of conditions. These conditions remain to be identified.

The present experiments attempted to replicate the procedures used by Hearst et al. (1964) as closely as possible. One obvious difference, however, was the difference in feeder durations in the present study (4 s) and those in the study by Hearst et al. (5 s). We wanted to maintain subjects at 75% of their free-feeding weights, as did Hearst et al., and based on the weight of our grain, the number of reinforcement opportunities in a session, and the amount our subjects typically gain in a 30-reinforcer session, we believed that the subjects experiencing the most frequent reinforcement (the VI 30-s groups) might surpass their target body weight. It is possible that our failure to replicate the results of Hearst et al. was due to this discrepancy in feeder durations. Note that the VI 240-s subjects that received extended training in Experiment 3 received a larger total amount of food than did the VI 240-s subjects in Experiment 1, and their generalization gradients were flatter. This increased amount of food may have had an effect similar to the increased amount of food that VI 240-s subjects earned in the Hearst et al. study (5 s, rather than 4 s, access per reinforcer). Although this possibility seems unlikely, it cannot be ruled out but can be tested empirically.

In summary, the present set of experiments failed to replicate the relation between rate of reinforcement and extent of generalization reported by Hearst et al. (1964). The variables responsible for the difference in effects reported in our experiments and those presented by Hearst et al. (1964) remain to be identified.

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APPENDIX

Repeated measures analysis of variance (ANOVA) was used to test for statistically significant differences in extent of absolute and relative generalization among or between groups. The between-subjects (group) factors

were VI parameter (Experiments 1 and 2) or amount of training (Experiment 3). The within-subject (stimulus value) factors were wavelength in nanometers (Experiments 1 and 3) or angle of orientation in degrees (Experiment 2). F values were considered statistically significant for $p < .05$. When statistically significant interaction (Group \times Stimulus Value) effects were found, Tukey post hoc testing was conducted to identify the stimulus values at which differences occurred. For the measure of relative generalization, because the peak of every gradient occurred at the training stimulus and always equaled 1.0, this value was excluded from statistical analyses (note the difference in degrees of freedom for absolute vs. relative generalization).

EXPERIMENT 1

Absolute Generalization

Group: $F = 2.145$, $p > .05$, $df = 2$
 Stimulus value: $F = 59.623$, $p < .05$, $df = 8$
 Group \times Stimulus Value: $F = 3.58$, $p < .05$,
 $df = 16^*$

*Tukey tests showed that the means of all groups were statistically significantly different at the 517-nm stimulus, and the mean for the VI 120-s group differed from the means for the other two groups at the 538-nm stimulus (critical difference > 16.036). No other statistically significant differences were revealed by Tukey post hoc testing.

Relative Generalization

Group: $F = 15.24$, $p < .05$, $df = 2$
 Stimulus value: $F = 144.75$, $p < .05$, $df = 7$
 Group \times Stimulus Value: $F = 5.476$, $p < .05$,
 $df = 14^*$

*Tukey tests showed that all means were statistically significantly different at the 517- and 538-nm stimuli. The mean for the VI 120-s group differed from the means for the other two groups at the 549- and 587-nm stimuli, and the means for the VI 30-s and VI 120-s groups differed at the 559-nm stimulus (critical difference > 3.442).

EXPERIMENT 2

Absolute Generalization

Group: $F = 4.737$, $p > .05$, $df = 1$
 Stimulus value: $F = 14.452$, $p < .05$, $df = 7$

Group \times Stimulus Value: $F = 2.393$, $p < .05$,
 $df = 7^*$

*Tukey tests showed that statistically significant differences occurred at the training stimulus and at stimuli oriented -23.5° , -41.5° , 21.5° , and 52.5° from the training stimulus (critical difference > 26.381).

Relative Generalization

Group: $F = 1.536$, $p > .05$, $df = 1$
 Stimulus value: $F = 30.968$, $p < .05$, $df = 6$
 Group \times Stimulus Value: $F = 4.003$, $p < .05$,
 $df = 6^*$

*Tukey tests showed that statistically significant differences occurred at stimulus values of 91.5° , -67.5° , -41.5° , and -23.5° (critical difference > 8.796).

EXPERIMENT 3

Absolute Generalization for VI 30-s Groups

Group: $F = 0.008$, $p > .05$, $df = 1$
 Stimulus value: $F = 33.895$, $p < .05$, $df = 8$
 Group \times Stimulus Value: $F = 0.140$, $p > .05$,
 $df = 8$

Relative Generalization for VI 30-s Groups

Group: $F = 0.129$, $p > .05$, $df = 1$
 Stimulus value: $F = 244.497$, $p < .05$, $df = 8$
 Group \times Stimulus Value: $F = 0.872$, $p > .05$,
 $df = 8$

Absolute Generalization for VI 240-s Groups

Group: $F = 8.558$, $p < .05$, $df = 1$
 Stimulus value: $F = 29.244$, $p < .05$, $df = 8$
 Group \times Stimulus Value: $F = 3.184$, $p < .05$,
 $df = 8^*$

*Tukey tests showed that the differences between means were statistically significant at all stimuli except the 576-nm wavelength (critical difference > 20.864).

Relative Generalization for VI 240-s Groups

Group: $F = 6.951$, $p < .05$, $df = 1$
 Stimulus value: $F = 47.193$, $p < .05$, $df = 7$
 Group \times Stimulus Value: $F = 1.302$, $p > .05$,
 $df = 7^*$

*Tukey tests showed that the differences between means were statistically significant at all stimuli except the 576-nm wavelength (critical difference > 7.197).